ON THE IDENTITY OF HELIOTROPISM IN ANIMALS AND PLANTS

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1. Since 1888 Loeb has in a number of publications expressed the idea that the apparent attraction of animals by light is in reality a phenomenon of automatic orientation of the animals by a source of light, comparable to or identical with the well-known phenomena of heliotropic orientation of plants. Thus he proved that sessile animal organisms react to light in the same way as sessile plants, namely, by bending or growing towards (or away from) a source of light; while motile animals move towards (or away from) a source of light as do the motile swarm spores of certain algae.

He based his theory of these reactions in animals on the following three assumptions. First, the light acts chemically upon the photosensitive elements of the surface of the body (eyes or skin). Second, symmetrical elements of the surface are identical chemically, so that if one source of light is given and symmetrical elements are struck at the same angle by the rays emanating from one source of light, the velocity of the photochemical reactions in the symmetrical elements is identical; if, however, they are struck at different angles, the velocity of chemical reactions is no longer the same in symmetrical elements.

Third, the velocity of photochemical reactions in the eyes or the skin influences (through the nerves or, as the case may be, other protoplasmic conductors) the tension of the muscles (or other contractile elements) connected with the photosensitive elements at the surface of the body. If symmetrical photosensitive elements are struck by the light at the same angle (and only one source of light exists), the symmetrical muscles of the body are influenced by the light in the same way and no change in the direction of the motion of the animal will occur. If, however, symmetrical photosensitive elements are struck at different angles the velocity of chemical reactions will not remain the same in the symmetrical elements and hence the tension of symmetrical muscles connected with these elements will not be the same; as a consequence, when the animal moves it must show a tendency to deviate from the straight line until finally its axis or plane of symmetry goes through the source of light again. When this happens the symmetrical elements of the photosensitive surface are again struck at the same angle by the light and there is now no more reason for the animal to deviate from this direction.

If this theory of heliotropism were correct, it was necessary to show that the law of photochemical action should hold for the heliotropic reactions of plants as well as of animals. This law (which was first established by Hankel for a narrow range of light intensity and extended by Bunsen and Roscoe over a wider range) says, that within certain limits the photochemical effect of light is equal to the product of intensity into the duration of illumination. Five years ago it was shown independently by Blaauw[1] and by Fröschl that the heliotropic reactions of plants obey the law of Bunsen and Roscoe, i.e., that the time required to bring about the heliotropic curvature of plants changes inversely with the intensity of illumination. A year ago Ewald and Loeb[2] showed that the same law holds also for the heliotropic curvature of an animal, namely, that of the polyps of *Eudendrium.*

2. Although the question of wave length does not enter into Loeb's theory of heliotropic orientation, it seemed of interest to compare the relative efficiency of the various parts of the spectrum upon the production of heliotropic curvatures in *Eudendrium* with that found for the heliotropic curvatures in plants. The most exact measurements on plants are those by Blaauw on the seedlings of *Avena.* Blaauw used a carbon arc spectrum, and found that the most efficient part of the spectrum was a region in the blue between 466 and 478 $\mu\mu$. In this region an exposure of only 4 seconds sufficed to call forth heliotropic curvatures in 50 percent of the stems of the seedlings. For longer waves a longer exposure was required, thus for a wave length of 499 $\mu\mu$ an exposure of 120 seconds, and for a wave length of 534 $\mu\mu$ an exposure of 6300 seconds. The yellow and red parts of the spectrum seemed absolutely ineffective.

We undertook last summer a series of experiments to ascertain the relative efficiency of the various parts of a carbon arc spectrum on the newly regenerated polyps of *Eudendrium.* The spectrum was thrown on a glass trough with parallel walls which contained a row of *Eudendrium* stems with a number of newly regenerated polyps. The position of each polyp was noted at the beginning of the experiment. Loeb and Ewald had found that the minimal time of exposure to produce heliotropic curvatures in more than 50 percent of the polyps is, for the same intensity of light, considerably greater than in the case of the seedlings of *Avena.* It required an exposure of at least 5 minutes in order to call forth heliotropic curvatures of the polyps of *Eudendrium* in the spectrum. The experiments were rendered difficult by the fact that the young polyps are very delicate and suffer easily. If a stem with sickly polyps is included in an experiment it is liable to disturb the

result. It was found that for the polyps of *Eudendrium* the most efficient region of the spectrum was in the blue in the neighborhood of 4735 angstrom units, which coincides with the region of maximal efficiency found for the seedlings of oats by Blaauw; while the region from 4900 to 5300 and from 4690 to 4400 or below was still effective, but less than the region in the blue near 4735. The red and yellow rays were practically ineffective, at least an exposure of over 5 hours to the red and yellow rays induced no curvature. The following table may serve to illustrate this statement.

The fact that in the first series (5-minute exposure) one polyp bent to the light in the red was, as the other experiments showed, merely

TIME	WAVE-LENGTH	COLOR	POLYPS BENT TO THE LIGHT		TIME	WAVE-LENGTH	COLOR	POLYPS BENT TO THE LIGHT	
	Angstroms		Fraction	Per cent		Angstroms		Fraction	Per cent
5 min.	6500 A	red	1/29	4	15 min.	6700–5400	red to yellowish green	0	0
	6000	yellow	0/4	0		5400–4900	yellowish-green and green	14/37	38
	5700	yellow	0/13	0		4900–4100	blue and violet	72/95	76
	5300–5345	yellowish-green	5/15	33		4100–3700	violet	14/30	46
	5100	green	3/12	25	$5\frac{1}{2}$ hrs.	6560–6000	red and orange	0/32	0
	4900	blue	11/32	35		5720	yellow	0/21	0
	4735	blue	30/49	62		5500–5300	green	3/13	24
	4690	blue	4/21	19		4950	blue	1/6	16
	4600	blue	5/22	23		4800	blue	7/16	44
	4400	blue	5/52	10		4700	blue	24/24	100

an accident. The region of maximal efficiency was in the blue of about 4735 A.

In the second series (15-minute exposure) no bending occurred in the red and yellow, in the green and bluish-green less than 50 percent bent to the light, in the blue 76 percent, and in the violet less than 50 percent.

The final series ($5\frac{1}{2}$-hour exposure) is given to illustrate the fact that even an exposure of $5\frac{1}{2}$ hours does not induce any bending in the red and yellow, while in the blue in the region of 4700 all the polyps were bent to the light. It should be mentioned that this effect was already reached in the region of 4700 A. in 160 minutes; after an exposure of 10 minutes already 73 percent were bent to the light.

These experiments show that the relative efficiency of the different parts of the spectrum of a carbon arc light for the production of heliotropic curvatures in the animal *Eudendrium* and in the seedlings of the plant *Avena* is practically identical.

[1] Blaauw, *Rec. des Trav. botaniques Néerlandais*, 5, 209 (1909).

[2] Loeb and Ewald, *Zentralbl. f. Physiol.*, 27, 1165 (1914).

ARCHAEOLOGY OF BARBADOS

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Our knowledge of the extent, character, and relationship of the prehistoric population of Barbados is very indefinite. It is not known whether the island was inhabited when discovered by the Portuguese in 1505, but there is every reason to believe it was, for a few aborigines still remained when it was colonized by the English over a century later. The existence of a native population is shown by Lignon's map published in 1657, thirty-one years after the English landed at Holetown, on which we find legends referring to Indian settlements. Several writers assert that while a limited number of Caribs were found by the first English colonists, these should be regarded as transient visitors from neighboring islands, rather than permanent occupants.

Archaeological evidences of a considerable prehistoric population in Barbados before the advent of Europeans are somewhat more definite than historical. These have already been presented by Greville T. Chester, and other archaeologists who have described many shell celts collected on Barbados. They have also brought to the attention of students numerous village sites that show evidences of a long continued occupation.

In a brief reconnaissance* made on Barbados by me in 1902, an examination was made of the archaeological evidence and data gathered bearing on the age and nature of the culture it revealed. An attempt is here made to determine the relation of this material to that found on the other West Indies. I am convinced from this examination that Barbados had a large local population in prehistoric times,

*These studies were made under the auspices of the Heye Museum of New York and the Bureau of American Ethnology of the Smithsonian Institution; a more complete account, amply illustrated, will be published later by the Bureau.